

AD_____

Award Number: W81XWH-04-1-0608

TITLE: Biomimetic Composite Scaffold for Breast Reconstruction Following Tumor Resection

PRINCIPAL INVESTIGATOR: Charles W. Patrick, Jr., Ph.D.

CONTRACTING ORGANIZATION: University of Texas M.D. Anderson Cancer Center
Houston, TX 77030

REPORT DATE: September 2005

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 01-09-2005		2. REPORT TYPE Final		3. DATES COVERED (From - To) 1 Sep 2001 – 31 Aug 2005	
4. TITLE AND SUBTITLE Biomimetic Composite Scaffold for Breast Reconstruction Following Tumor Resection				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER W81XWH-04-1-0608	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Charles W. Patrick, Jr., Ph.D. E-mail: cpatrick@mdanderson.org				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Texas M.D. Anderson Cancer Center Houston, TX 77030				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The overall, long-term objective of this innovative proposal was to develop a clinically translatable strategy to restore the breast mound following mastectomy or lumpectomy such that patient quality of life and outcomes are markedly improved. We hypothesized that a novel composite material consisting of silk fibroin and chitosan will act as a biomimetic scaffold amenable to in vivo adipogenesis. The specific aims (SAs) of this 1-year proposal were to (1) develop a rational portfolio of composite materials by combining silk fibroin and chitosan under various fabrication conditions, (2) characterize the materials using defined metrics and select a set of candidate materials based on mechanical and ultrastructural properties, (3) determine in vitro cytocompatibility and preadipocyte seeding parameters of the candidate materials, and (4) determine in vivo applicability of the preadipocyte-seeded candidate materials using a short-term rat subcutaneous pocket assay. All aims have been accomplished within the 1-year time frame. Academic outcomes include the current preparation of several manuscripts, several presentations at national/international conferences, and the training of several research interns.					
15. SUBJECT TERMS biomaterial, scaffolds, preadipocytes, breast reconstruction					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 39	19a. NAME OF RESPONSIBLE PERSON USAMRMC
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code)

Table of Contents

Cover.....	1
SF 298.....	2
Introduction.....	4
Body.....	4
Key Research Accomplishments.....	5
Reportable Outcomes.....	6
Conclusions.....	6
Appendices.....	6

INTRODUCTION

The overall, long-term objective of this innovative proposal is to develop a clinically translatable strategy to restore the breast mound following mastectomy or lumpectomy such that patient quality of life and outcomes are markedly improved. Local and wide tumor resection followed by breast reconstruction continues to be a prominent component of managing the breast cancer patient. Despite tremendous advances in surgical techniques and ancillary support devices, severe reconstructive limitations exist that ultimately affect the physical, psychological, and emotional well being of patients.

The increased rate of breast cancer over the past two decades and the 174% increase in the rate of breast reconstruction over the last decade provides an impetus to overcome current breast cancer management limitations. A timely, novel concept for a new rehabilitative strategy has emerged over the last six years. Namely, the field of tissue engineering is attempting to overcome contemporary reconstructive limitations by developing strategies that permit patients to regrow their own breast mounds using autologous adipose tissue cells. The feasibility of this concept has been proven in a small animal model using synthetic materials. Achieving this long-term objective requires sophisticated, biomimetic materials to be used as appropriate scaffolds for seeding preadipocytes (adipose tissue precursor cells) and for appropriately modulating preadipocyte molecular and cellular dynamics.

This proposal concentrates on developing an innovative biomimetic scaffold materials by combining two natural polymers: silk fibroin (from *Bombyx mori* silk worm) and chitosan (from crustacean shells). Both materials are well tolerated in the body (more so than synthetic materials) and mimic human extracellular matrix protein structure. For example, silk fibroin structurally mimics collagen I. Preliminary studies demonstrate that these materials can be combined to yield novel scaffolds. This multidisciplinary application employs principles of bioengineering, synthetic polymer chemistry, and preadipocyte cell biology.

We hypothesize that a novel composite material consisting of silk fibroin and chitosan will act as a biomimetic scaffold amenable to in vivo adipogenesis. The specific aims (SAs) of this 1-year proposal are to (1) develop a rational portfolio of composite materials by combining silk fibroin and chitosan under various fabrication conditions, (2) characterize the materials using defined metrics and select a set of candidate materials based on mechanical and ultrastructural properties, (3) determine in vitro cytocompatibility and preadipocyte seeding parameters of the candidate materials, and (4) determine in vivo applicability of the preadipocyte-seeded candidate materials using a short-term rat subcutaneous pocket assay.

BODY

TASK 1: DEVELOP A RATIONAL PORTFOLIO OF COMPOSITE MATERIALS BY COMBINING SILK FIBROIN AND CHITOSAN UNDER VARIOUS FABRICATION CONDITIONS (Months 1-3):

- a. Fabricate composite materials by varying polymer chemistry conditions
 - b. Optimize crosslinking chemistry
- TASK 2: CHARACTERIZE THE MATERIALS USING DEFINED METRICS AND SELECT A SET OF CANDIDATE MATERIALS BASED ON MECHANICAL AND ULTRASTRUCTURAL PROPERTIES (Months 4-5):
- a. Scanning electron microscopy
 - b. Optical microscopy
 - c. Mechanical testing
- TASK 3: DETERMINE IN VITRO CYTOCOMPATIBILITY AND PA SEEDING PARAMETERS OF THE CANDIDATE MATERIALS (Months 6-8):
- a. Seed composite with cultured rat preadipocytes (PAs)
 - b. Determine PA viability
 - c. Determine PA proliferation and compare results with standard 2D proliferation on tissue culture plastic
 - d. Determine the degree of PA differentiation using Oil Red O staining
- TASK 4: DETERMINE IN VIVO APPLICABILITY OF THE PA-SEEDED CANDIDATE MATERIALS USING A SHORT-TERM RAT SUBCUTANEOUS POCKET ASSAY (Months 9-12):
- a. Optimum scaffold preparation
 - b. PA preparation
 - c. Implantation of PA-seeded scaffolds for (1 and 2 weeks)
 - d. Specimen harvest and histological processing
 - e. Quantitative histomorphometry

All tasks were successfully completed within the 1-year time frame and specific accomplishments and outcomes are listed below. The Appendices contain details of experiments via two submitted manuscripts.

KEY RESEARCH ACCOMPLISHMENTS

- Polymer chemistry was successful in generating composite biomimetic scaffolds.
- Biological and physical assessment of the scaffolds was completed.
- In vitro and in vivo experiments were completed.

- The project was successful and provides outstanding preliminary to garner more substantial and longer duration funding from National Institutes of Health and other funding sources.

REPORTABLE OUTCOMES

- Project was partially conducted by three summer research interns as part of their training in the Laboratory of Reparative Biology & Bioengineering's Summer Bioengineering Research Internship program.
 - Lindsay Black, University of Texas at Austin
 - Barret Cromeens, Southwestern University
 - Guido Santacana, University of Puerto Rico
- Presentations:
 - Wu, X., Black, L., Satacana, G., Patrick Jr., C.W., Assessment of glutaraldehyde-crosslinked collagen/chitosan scaffold for adipose tissue engineering, Tissue Engineering Society International, Shanghai, China, 10/05.
- A manuscript detailing the summer research internship program, in which this proposal's work is included, has been submitted (*International Journal of Engineering Education*). Research has just been completed and manuscripts are currently being written.
 - Wright, A., Frye, C., Wu, X., Mathur, A., Patrick Jr., C.W., Biomedical engineering summer research internships within a comprehensive cancer center: A 10 year experience, *International Journal of Engineering Education* (submitted)
 - Wu, X., Black, L., Satacana, G., Patrick Jr., C.W., Assessment of glutaraldehyde-crosslinked collagen/chitosan scaffold for adipose tissue engineering, *Tissue Engineering* (in preparation)

CONCLUSIONS

The successful accomplishment of the tasks outlined above provide a strong foundation to proceed with the following:

- Incorporation of growth factors
- Conduct in vivo studies (i.e., transplant preadipocyte-loaded PEG hydrogels and generate adipose tissue in vivo).
- Apply for continued extramural funding

APPENDICES

A.S. Wright, X. Wu, C.A. Frye, A.B. Mathur, C.W. Patrick Jr., Biomedical Engineering Summer Research Internships Within A Comprehensive Cancer

Center: A 10 Year Experience, *International Journal of Engineering Education*,
submitted

(Other manuscripts currently being written)

**Biomedical Engineering Summer Research Internships Within A Comprehensive Cancer
Center: A 10 Year Experience**

A.S. Wright, X. Wu, C.A. Frye, A.B. Mathur, C.W. Patrick Jr.

Laboratory of Reparative Biology & Bioengineering, Department of Plastic Surgery, The
University of Texas M.D. Anderson Cancer Center

Address correspondence to:

Charles W. Patrick Jr., Ph.D.

Laboratory of Reparative Biology & Bioengineering, Unit 602

P.O. Box 301402

The University of Texas M.D. Anderson Cancer Center

Houston, Texas 77230-1402

Tel: (713) 563-7565

Fax: (713) 563-0231

E-mail: cpatrick@mdanderson.org

ABSTRACT

A Biomedical Engineering Internship Program conducted within a Comprehensive Cancer Center over a 10 year period was assessed and evaluated in this article. Although this is a non-traditional location for an internship, it is an ideal site for a multidisciplinary training program for biomedical engineering students. We made a systematic and comprehensive effort to assess and evaluate the impact of the internship experiences on trainees' learning. The curriculum centered around six content categories: didactic classes, research skills, clinical experience, communication, tours and demonstrations, and social activities. The students were assessed for this study via three methods: demographics, selected response surveys, and academic outcomes. The assessment data indicate that the Biomedical Engineering Internship Program has been successful in creating a learning environment that integrates medical principles and engineering fundamentals.

Keywords: assessment, evaluation, engineering education, internship

I. INTRODUCTION

The University of Texas M.D. Anderson Cancer Center (UTMDACC) is a component of the University of Texas System. It is one of the nation's original three Comprehensive Cancer Centers designated by the National Cancer Act of 1971 and is one of 52 Comprehensive Cancer Centers today. In 1996, the Laboratory of Reporative Biology & Bioengineering (LRBB) was established at UTMDACC to develop translatable solutions for clinical problems and limitations and train the next generation of scientists in a multidisciplinary, discovery-centered environment. As part of LRBB's educational mission, a formal Biomedical Engineering Summer Internship Program was initiated for undergraduate, medical, and senior high school students. Trainees are competitively selected from local, interstate, and international universities and medical schools through collaborative links established by UTMDACC and/or LRBB. The internship is administered by engineering faculty within the cancer center and trainees are co-mentored by engineering and clinical faculty.

The internship within the LRBB serves a critical purpose for trainees participating in or interested in biomedical engineering or quantitative-based careers by providing an opportunity to learn and integrate medical principles with engineering fundamentals. A database of trainee demographics and tangible learning outcomes has been maintained. A decade has passed since the internship program began. In this study, we make a systematic and in depth effort to assess and evaluate the program and to measure the impact of the experiences on trainee learning.

II. DESCRIPTION OF CURRICULUM

The ultimate goal of the internship is to improve student learning. The intensive 10-week curriculum is designed to immerse trainees in a hands-on, practical environment that enhances

the skill sets required to develop biomedical engineering solutions for clinically relevant problems. In addition, the internship aids trainees in career path decisions by highlighting their strengths, weaknesses, likes, and dislikes. Further, the internship provides trainees the opportunity to learn, practice, and demonstrate elements of ABET Criterion 3 [2]. Although the LRBB is not within an engineering degree granting institution, it is of critical importance to engineering departments who send trainees that the internship possess aspects of ABET Criterion 3. There are numerous classification strategies employed to describe educational internships. The curriculum described and assessed herein concentrates on six content categories, each of which is briefly presented.

A. Didactic Classes

At the beginning of the internship, trainees participate in several laboratory and institutional didactic classes aimed at enhancing awareness of critical issues relevant to the conduct of research. Trainees participate in a 1-day laboratory orientation that covers laboratory safety and proper laboratory etiquette (i.e., how to properly handle equipment, clean up, etc.). During orientation each trainee is also given their research expectations and how to properly record data and findings in their laboratory notebook.

In addition to lab-based classes, trainees matriculate through two institution-based classes: Laboratory Safety Training and Animal Care and Use Training. The Laboratory Safety Training covers health, safety, and environmental issues related to research processes and activities. Animal Care and Use Training entails the proper techniques for working with research animals. The class uses both multi-media materials as well as hands-on training so that

the trainees are well prepared while working in Veterinary Medicine facilities. Further training on clinic and operating room etiquette are administered by individual faculty.

Cell culture training presents sterile techniques as well as the necessary tools for cell culture. If the trainee will be working with cell culture in the research project they have been assigned, they must demonstrate proficiency with the cells by growing a cell line and constructing a cell growth curve. Individualized training sessions are administered by laboratory staff and/or faculty for use of specialized equipment or protocols. This training includes the principles and practical applications of fluorescence microscopy, atomic force microscopy; total internal reflection fluorescence microscopy; digital image acquisition and analysis; and biomaterial manipulation, scaffold fabrication and characterization.

B. Research Skills

The trainees are assigned a research project at the beginning of the internship in one of three broad areas: regenerative medicine, nanomedicine, and core research support. Projects are carefully designed and matched according to the trainee's interest as well as their relevant background. The majority of individual assignments are part of larger projects that require teamwork among the trainees. Research projects serve the dual purpose of enhancing trainees' research skill sets and assisting the LRBB with the ultimate goal of developing clinically translatable products and enhancing patient quality of life. Skills sets enhanced by conducting research projects include analytical skills, problem solving and decision-making, project management, teamwork, and technical aspects of the research process [4]. Table 1 defines each of these skills within the context of the 10-week internship. A strong work ethic is practiced, requiring trainees to work efficiently and effectively on their projects daily.

C. Clinical Experience

One of the advantages of conducting a biomedical engineering internship within a Comprehensive Cancer Center is the direct access to and integration with clinical and operative facilities. Many trainees enroll in the internship with future aspirations of medical school. Hence, clinical experiences are invaluable for crystallizing medical career interests as well as linking trainee research projects to realized clinical limitations. Trainees are constantly exposed to patients and realize the need to improve surgical outcomes and patient quality of life.

The majority of trainees are co-mentored with both a biomedical engineer and a physician scientist. This allows trainees to maintain clinical relevance and learn how to communicate across disparate fields. Trainees are permitted to shadow clinical faculty during their clinic hours to observe patient-physician interactions, surgical planning, and postoperative outcomes, as well as learn about HIPPA, IRB, and other regulations physicians must abide. In addition, trainees are permitted to observe invasive operative cases. This allows trainees to observe hands-on operative limitations and ergonomics- two aspects critical to consider when designing clinically translatable strategies.

Trainees are classified as “observers”, preventing direct contact with patients in the operating room. However, they are permitted to learn and practice surgical skills in the animal surgery facility. Faculty routinely have trainees assist with animal surgeries where they learn how to suture, move and work in a sterile field, correctly name and handle surgical instruments, conduct simple dissections, and retract in more complicated surgical and microsurgical procedures. Participation in animal studies also permits trainees to gain the ability to make measurements on and interpret data from living systems as well as address the problems associated with the interaction between living and non-living materials.

D. Communication

At LRBB, oral and written communication occurs via various modalities since biomedical engineering as a practicing profession requires effective interdisciplinary communication. Trainees are required to write effectively in levels ranging from weekly summaries to formal technical reports and be able to present their work orally in diverse meeting formats.

Laboratory notebooks are issued at the beginning of the internship and each trainee is responsible for journaling their work daily. Trainees are required to document meeting notes, literature reviews, experimental designs, data, and articulated conclusions in a clear and complete manner. An umbrella confidentiality agreement is signed at the beginning of the internship to protect the laboratory's intellectual property. This permits trainees to make copies of their laboratory notebooks for future class work and reports. Laboratory notebooks are reviewed and critiqued weekly by laboratory staff.

In addition to laboratory notebooks, trainees are required to utilize correct e-mail etiquette. Specifically, they are instructed to use e-mail for concise information dissemination, file transfers, and meeting scheduling rather than use e-mail for open-ended discussion or "e-talking" [3]. Correct grammar as opposed to text message language is required. The written communication component of the curriculum also stresses appropriate methods for presenting data at team meetings so that data can be properly interpreted and conclusions expressed. Methods typically include various forms of graphical and statistical presentation. Trainees are also required to present a final written report of their research project using a peer-reviewed journal format. In some cases, research progresses to the point that trainees have the opportunity to participate in writing a conference abstract and/or a manuscript.

Numerous opportunities exist for trainees to enhance oral communication skills. Regular meetings with research advisors permits trainees to practice articulating ideas in a clear and concise fashion, using facts to reinforce points, and asking questions to obtain feedback. Trainees are required to communicate effectively across various scales: peers, advisors, small teams, and large audiences. In addition, trainees learn about the challenges realized and skills required to communicate with multidisciplinary teams consisting of engineers, physicians, and life scientists. At the end of the internship, trainees participate in a formal 1-day symposium where they present their research to peers and faculty using PowerPoint and other media formats. Trainees are given constructive criticism on their presentation skills, including effectiveness of media utility, presentation speed and volume, proper use of laser pointer, and ability to handle questions.

E. Tours and Demonstrations

As a comprehensive cancer center, the UTMDACC possesses many facilities for trainees to tour to enhance their knowledge base and research awareness. A tour of the Veterinary Surgery facility educates trainees on the wealth of small and large animal models employed, the ethical care and procedures required for a AAALAC accredited facility, and the imaging and surgical resources available for animal model-based research. In addition, a tour of UTMDACC's Medical Library demonstrates the most efficient search methods for locating materials within all of the Texas Medical Center's libraries.

F. Social Activities

The trainees are given multiple opportunities to interact not only within the laboratory settings, but on much broader scopes as well. Each trainee attends UTMDACC's New Hire Orientation at the beginning of the internship. During the orientation, there is potential for the trainees to meet and interact with employees from different departments as well as different job classifications. The trainees also participate in regularly scheduled formal lab meetings in which data are presented and disseminated to the laboratory staff, trainees, and faculty. There are also informal group meetings ("coffee meetings") in which diverse scientific and administrative topics are discussed in the absence of faculty.

Throughout the internship several social functions are planned to ensure that the trainees are also enjoying their time and to provide informal venues to foster faculty-trainee interactions. Breakfasts, lunches, "munchie" days and/or movie nights are planned throughout the course of the summer. At the end of the internship, a laboratory BBQ is hosted by faculty to celebrate the trainees' internship experience.

III. METHODS OF ASSESSMENT

In order to obtain a better understanding of the Biomedical Engineering Internship Program, three methods of analysis are employed to assess and evaluate the internship: trainee demographics, selected-response surveys, and academic outcomes. Archiving of laboratory notebooks and oral presentations permits generation of trainee portfolios as a direct assessment tool. However, portfolios are not included herein as they do not lend themselves to presentation in manuscript format. In this study, assessment is defined as the act of collecting data or

evidence, and evaluation is defined as interpretations made of the collected assessment evidence [1].

A. Demographics

A database has been maintained of all internship trainees since 1996. The database records a myriad of trainee descriptors. UTMDACC is an academic hospital and does not possess an engineering or medical school program of its own. Hence, all trainees enroll from external, collaborative academic entities. Trainee demographics are stratified according to gender, race/ethnicity, academic level (medical, undergraduate, or high school student), and location of academic residence. In addition, the cumulative number of trainees is plotted against time. Trainees are further stratified according to one of the three aforementioned project areas.

B. Selected-response surveys

A selected-response survey is a survey in which subjects respond by selecting their answers from a list of predetermined responses [1]. A selected-response survey was chosen rather than an open-ended survey because the open-ended surveys (i.e., unstructured, short answer responses) would vary too much given the broad background and experiences of the trainees [1]. The survey assesses trainee perceptions of the impact of the internship on several skill sets and its perceived importance on learning outcomes. An example post-internship survey is found in Appendix I. A Likert ordinal scale is employed for question responses (e.g., very little=1,..., very much=5). The Likert technique presents a set of attitude statements. Subjects are asked to express agreement or disagreement on a five-point scale. Each degree of agreement is given a numerical value from one to five. Thus, a total numerical value can be calculated from

all the responses. A pilot survey was conducted to eliminate any ambiguous statements, negative statements, or statements which might seem unduly “leading”.

Since surveys are a self-report instrument, the quality of the information acquired depends on the extent to which subjects choose to respond honestly. To assist in data integrity, surveys are administered in paper/pencil format in the absence of faculty and a non-faculty administrative assistant collects the surveys and enters responses in a database. Low response rates obviously threaten the validity of a study. Controls were established to encourage participants to respond, including the non-faculty administrative assistant sending follow-up reminders and, more recently, instituting survey completion as part of the trainee’s formal check-out procedure.

C. Academic outcomes

Despite the internship lasting only 10-weeks, trainees tend to be quite productive in acquiring and analyzing data. As a matter of laboratory policy, trainees who substantially participate in (a) conception and design, or analysis and interpretation of data, and (b) drafting the article or revising it critically for important intellectual content are listed as co-authors on manuscripts and conference abstracts. The number of manuscripts and oral/poster presentations with trainees listed as co-author are assessed for the past ten years.

IV. RESULTS & DISCUSSION

LRBB’S Summer Biomedical Engineering Internship has enrolled 51 trainees over the past 10 years. Figure 1 illustrates the cumulative number of trainees over the decade. Increases in trainee number followed an increase in laboratory space assigned to the LRBB. A total of 30

trainees responded to the post-internship survey, yielding a response rate of 59%. In the past, surveys were mailed after the trainees returned home. An 88% response rate has been realized the past 2 years once survey completion was instituted as a part of the trainees' formal check-out procedure. Demographic assessment for all trainees is 100% complete.

A. Demographics

Trainee gender was 61% male and 39% female. The ethnic distribution of trainees was 58% White, 22% Asian, 16% Hispanic, and 4% African American. The gender and ethnicity statistics track with the undergraduate demographics of local universities (Rice University and University of Texas at Austin, university web-based data not shown). Trainees were predominantly undergraduate students (53%), and the remainder medical (27%) and high school students (20%). The largest segment of trainees enrolled from Texas institutions (78%) and 8% from international institutions (Table 2). Of the Texas institutions, Rice University and University of Texas at Austin provided the majority of trainees (45%).

Research projects were assigned in three broad areas. Trainees largely selected regenerative medicine projects (65%), followed by core support (23%) and nanomedicine (12%). Nanomedicine has only been an option for trainees the past two years and it is anticipated that this project area will increase in popularity over the next 5 years. Table 3 list representative trainee research projects that fall under each project area.

B. Selected-response surveys

The aspect of the internship program most difficult to measure is the quality of the trainees' individual experience and research project. Trainees necessarily enter the internship

with a variety of personal and academic backgrounds, receive guidance from faculty mentors with different styles and goals, and conduct research at different levels of sophistication. Hence, there are numerous variables that make it difficult to generate a standard measure. A selected-response survey was employed to capture a measure of the trainees' perceived experience. It is recognized in interpreting the data that trainees do not typically possess the long-term, objective, calibrated perspective on their performance level that faculty do.

Trainees were asked to participate in a 25 question selected-response survey at the completion of the internship. A copy of the survey is found in Appendix 1. Figure 2 illustrates the trainees' perception on how the internship enhanced six critical skill areas. The average Likert scores for all skills were between 4 (Much) and 5 (Very Much). The lowest skill area was Creative Problem Solving (score=4.04) and is perhaps an area that needs to be addressed more effectively during future internships.

Trainees were queried to determine if they perceived 12 internship activities beneficial to their experience (Figure 3). With the exception of two activities, all possessed average Likert scores between 4 and 5. On-line Library Skills and Laboratory Safety Training yielded Likert scores between 3 (Neutral) and 4 (Much). Interestingly, these are the only two activities not directly taught by LRBB staff or faculty. Rather, they are general institutional courses. Upon arrival, the majority of trainees tend to be quite facile with on-line search skills and most have taken a laboratory safety class within their home academic institution. It is advantageous to ensure that all trainees possess the same foundation, so deletion of these two activities is not advisable. Laboratory Safety Training is an institutional requirement and can not be removed from the curriculum. The lower scores suggest that augmentation of the institution-based activities may be necessary to challenge the trainees.

Four additional questions were asked of trainees and response results are presented in Figure 4. Trainees perceived that they were effectively mentored by LRBB staff and participating faculty, attested with Likert scores ranging between 4 and 5. The scores for faculty mentoring bodes well, suggesting that despite the fact they possess disparate disciplines and goals, the faculty are well calibrated and committed to the internship program. Student “word of mouth” is often employed as a qualitative measure of course success and/or trainee interest. The Likert score for trainee internship recommendation suggests that the biomedical engineering internship is successful. This tracks with anecdotal evidence of trainees requesting an internship application based on a classmates suggestion. Finally, the internship proved useful to the trainees in crystallizing their career path and goals. Verbal statements of trainees have been clear on this point. Example statements include: (a) “I know now that I don’t want to do research”, (b) “I definitely want to go to medical school”, and (c) “I am very interested and prefer to go to graduate school in biomedical engineering versus other disciplines”.

C. Academic outcomes

Academic outcomes were measured based on significant contribution of the student’s work towards national and international publications in journals and presentations at meetings/conferences. There were 28 publications and 36 presentations that resulted from the work conducted by students in the LRBB over the last 10 years. The raw data does not directly reflect the contribution of more than one summer intern that co-authored the presentation or publication with another summer intern. Trainees also presented seminars and papers at the end of the summer program; these are not included in the academic outcome data.

V. SUMMARY

Cooperative education and internships have traditionally demonstrated a positive impact on trainee academic performance and experience. This article assessed and evaluated a biomedical engineering internship conducted within a comprehensive cancer center over a 10 year period. This is a non-traditional location for an internship, but submits that it is an ideal site for a biomedical engineering summer internship. Based on the assessment data and evaluation presented, the internship has been quite successful, providing a discovery-centered creative environment where medical principles are integrated with engineering fundamentals.

Although the program's initial decade has proven successful, several program extensions can be implemented. First, assessment herein largely focused on one constituency of the internship, namely the trainees. The mentoring faculty represents the second constituency and need to participate in assessment as well. In addition, the assessment methods employed are descriptive and, although useful, more outcome-driven and direct methods must be employed to enhance evaluation and meet ABET requirements. Further, future curriculum modifications should take advantage of new learning sciences, such as implementing adaptive expertise from the How People Learn (HPL) model.

ACKNOWLEDGEMENTS

We acknowledge the assistance of faculty and staff from the Department of Plastic Surgery and the Department of Biostatistics and Applied Mathematics, The University of Texas M.D. Anderson Cancer Center; the Department of Biomedical Engineering, The University of Texas at Austin; and the Department of Chemical Engineering and the Department of Bioengineering, Rice University for their assistance in co-mentoring summer interns. In

addition, we acknowledge the active participation of the trainees who participated in the summer internship. The internship has been funded by the following sources: Mr. & Mrs. Robert A. Buschman, Mr. Charles Butt, the Carol B. & Florence E. King Foundation, the National Institutes of Health, the University of Texas Center for Biomedical Engineering, and the University of Texas M.D. Anderson Cancer Center.

REFERENCES

- [1] Olds, M.B., Moskal, B.M, and Miller, R.L., "Assesment in engineering education: Evolution, approaches, and future collaborations," *Journal of Engineering Education*, Vol . 94, 2005, pp. 13-25.

- [2] <http://www.abet.org>.

- [3] Booher, D. *E-Writing: 21st-century tools for effective communication*, Pocket Books, , 2001.

- [4] McGourty, J, Sebastian, C., and Swart, W., "Performance measurement and continuous improvement for undergraduate engineering education," *Proceedings of the Frontiers in Education Conference*, Pittsburgh, PA, November, 1997.

AUTHORS' BIOGRAPHIES

Charles W. Patrick Jr. Ph.D. is Associate Professor at the Laboratory of Reparative Biology & Bioengineering, Department of Plastic Surgery, the University of Texas M.D. Anderson Cancer Center. He currently serves as Director of the Laboratory of Reparative Biology & Bioengineering and Associate Director of the University of Texas Center for Biomedical Engineering. In addition, he possesses active adjunct positions at Department of Biomedical Engineering, University of Texas at Austin; Department of Bioengineering, Rice University; and the University of Texas Graduate School of Biomedical Sciences where he teaches classes and mentors students. He received a B.S.Ch.E from Louisiana State University in 1990 and a Ph.D. in chemical engineering from Rice University in 1994. Following a postdoctoral fellowship in tissue engineering, he joined the University of Texas M.D. Anderson Cancer Center in 1996. His research interests include tissue engineering, angiogenesis, and biomaterials. He is a charter member of Tissue Engineering Society-International and a member of the Biomedical Engineering Society. Dr. Patrick also serves as Associate Editor for *Annals of Biomedical Engineering*.

Anshu B. Mathur, Ph.D. is Assistant Professor at the Laboratory of Reparative Biology & Bioengineering, Department of Plastic Surgery, the University of Texas M.D. Anderson Cancer Center. She currently serves as Associate Director of the Laboratory of Reparative Biology & Bioengineering and is a member of the University of Texas Center for Biomedical Engineering. In addition, she possesses active adjunct positions at Department of Biomedical Engineering, University of Texas at Austin and Department of Bioengineering, Rice University where she teaches classes and advises undergraduate and graduate engineering students. She received a

B.S. in Biochemistry, a B.S. in Polymer Chemistry, and a M.S. in Polymer Chemistry from North Carolina State University, and a M.S. in Biomedical Engineering from Duke University. She received a Ph.D. in Biomedical Engineering from Duke University in 2001. After working as a Patent Technology Consultant for Spore LLC, she joined the University of Texas M.D. Anderson Cancer Center in 2003. Her research interests include nanomedicine and regenerative biomaterials. She is a member of the Biomedical Engineering Society and Society for Biomaterials.

Cynthia A. Frye, M.S. is Laboratory Manager at the Laboratory of Reparative Biology & Bioengineering, Department of Plastic Surgery, the University of Texas M.D. Anderson Cancer Center. She received a B.S. in Food Science from Michigan State University and a M.S. in Cell Biology from the University of Houston- Clear Lake. She is responsible for managing laboratory staff and trainees, mentoring trainees, and teaching specialized laboratory courses.

Xuemei Wu, M.D. is a Senior Research Assistant at the Laboratory of Reparative Biology & Bioengineering, Department of Plastic Surgery, the University of Texas M.D. Anderson Cancer Center. She received a M.D. from Norman Bethune University of Medical Sciences, Changchun, China. She is responsible for mentoring trainees and teaching specialized laboratory courses.

Amy Wright, B.B.A. is the Internship Coordinator at the Laboratory of Reparative Biology & Bioengineering, Department of Plastic Surgery, the University of Texas M.D. Anderson Cancer Center. She received her BBA from LeTourneau University. She is responsible for compiling and maintaining the internship database and all administrative aspects of the internship.

TABLES

Table 1: Skill sets and learning outcomes for the research component of the internship curriculum.

Skill Set (ABET Criterion 3 [2])	Learning Outcomes
<i>Analytical skills</i> (a, e, k)	<ul style="list-style-type: none"> • Critical think through multiple variables, alternative solutions, and feasibility • Translation of theory to practical application • Analyze, interpret, and statistically evaluate data • Order of magnitude judgments and use of measurement units and conversions • Integration of past knowledge with new information
<i>Problem solving and decision making</i> (e)	<ul style="list-style-type: none"> • Develop solutions without making premature conclusions • Creativity • Learn from failure
<i>Project management</i> (d, g)	<ul style="list-style-type: none"> • Prioritization of tasks to meet project milestones • Real-time corrective action • Effective multi-tasking • Clarification of requirements and milestones • Balance team vs. individual tasks
<i>Teamwork</i>	<ul style="list-style-type: none"> • Contribute actively to complete a project

(d, g)	<ul style="list-style-type: none"> • Joint and individual accountability • Cooperation and communication • Reconcile differences among team members • Sharing of information and laboratory resources
<i>Research process</i> (a, b, c, f, h, j, k)	<ul style="list-style-type: none"> • Effective use of computer resources • Effective use of databases (e.g., PubMed) • Proper experimental design • Develop and test hypotheses • Specify and obtain required laboratory supply and equipment resources • Write and follow protocols • Properly collect, measure, and document data from the lab, clinic, and/or animal facilities

Table 2. Origin of Country and State of trainees.

<i>United States</i>		<i>International</i>	
Texas	40	Puerto Rico	3
Pennsylvania	2	Germany	1
Connecticut	1		
Maryland	1		
Michigan	1		
Missouri	1		
Oklahoma	1		
<i>Total</i>	<i>47</i>		<i>4</i>

Table 3. Representative research titles for each project area.

<i>Regenerative Medicine</i>	<ul style="list-style-type: none"> • 3D morphometric analysis of revascularization • Adipose tissue engineering within perfused bioreactors • Characterization of an ovine model for bone tissue engineering • Fabrication and implantation of biodegradable nerve conduits for peripheral nerve regeneration • Fabrication of collagen/chitosan scaffolds for adipose tissue engineering • Structural and mechanical characteristics of silk fibroin and chitosan blend scaffolds for tissue regeneration • Abdominal wall reconstruction with silk fibroin-chitosan blend biomaterials
<i>Nanomedicine</i>	<ul style="list-style-type: none"> • Dielectrophoretic nano-fibrillar alignment in silk fibroin-chitosan blend scaffolds for blood vessel guidance and assembly. • Characterization of nano-mechanical properties of silk fibroin/chitosan scaffolds to regulate endothelial cell focal adhesion behavior. • Modulation of endothelial cell adhesion on silk fibroin and chitosan surfaces. • Liposomal nano-coatings for long term and targeted therapeutic local delivery • Promotion of Stable Vasculature via siRNA Technology
<i>Core Support</i>	<ul style="list-style-type: none"> • Development and validation of GPDH assay • Development and validation of human leptin assay • Development of software image analysis scripts for quantitative histomorphometry. • Equipment setup and calibration of TIRFM system • Equipment setup and development of Western assays

FIGURE LEGENDS

Figure 1. Cumulative number of trainees over the past decade. Vertical broken lines delineate increases in laboratory space.

Figure 2. Likert score for the selected-response survey questions concentrating on six skill sets. Data represent mean \pm SEM.

Figure 3. Likert score for the selected-response survey questions concentrating on the benefit of 12 activities. Data represent mean \pm SEM.

Figure 4. Likert score for the selected-response survey questions concentrating on mentoring, recommendation, and career path. Data represent mean \pm SEM.

APPENDICES

Appendix 1: Selected-Response Survey



INTEGRATIVE BIOMEDICAL ENGINEERING SUMMER INTERNSHIP PROGRAM SURVEY

**The Laboratory of Reparative Biology & Bioengineering
University of Texas M.D. Anderson Cancer Center**

Name:

Summer Attended:
(e.g., 6/05-8/05)

INSTRUCTIONS: Please answer the following questions about your summer research internship experience to the best of your recollection. Type an X in the box related to your answer according to the provided scale. In select questions, NA may be appropriate for your summer experience.

Very Little 1	Little 2	Neutral 3	Much 4	Very Much 5	N/A
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

1. The summer internship program helped to define my career path/goals.

2. Participating in the summer internship program enhanced my skills in the following six areas:

Analytical Skills

Apply logic in solving problems and analyze problems from different points of views.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

Communication

Articulates ideas in a clear and concise fashion and use facts to reinforce points.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

Creative Problem Solving

Develop many potential solutions while discouraging others from rushing to premature conclusions.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

Research Skills/Technical Competence

Demonstrate a basic understanding of fundamental biomedical engineering and/or laboratory principles.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

Self Learning

Learn independently and continuously exceed basic requirements of an assignment.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
--------------------------	--------------------------	--------------------------	--------------------------	--------------------------	--------------------------

Teamwork

Contribute a fair share to the completion of the project, encourage everyone to participate, cooperate with the team members, share information, and help reconcile differences of opinions among fellow team members.

Very Little 1	Little 2	Neutral 3	Much 4	Very Much 5	N/A

3. The program helped to improve my grades the following semester.

--	--	--	--	--	--

4. I used my summer research as a basis for other projects (*e.g., sr. design, papers, posters, etc.*)

--	--	--	--	--	--

5. I have or would recommend our lab to other students.

--	--	--	--	--	--

6. I found the following beneficial to my summer internship experience:

Tour of Veterinary Facilities

--	--	--	--	--	--

Operating Room Observation

--	--	--	--	--	--

Laboratory Orientation

--	--	--	--	--	--

Laboratory Safety Training

--	--	--	--	--	--

On-line Library Skills

--	--	--	--	--	--

Tissue Cultures/ Sterile Technique

--	--	--	--	--	--

Technical Laboratory Skills

--	--	--	--	--	--

Participation in Group Lab Meetings

--	--	--	--	--	--

Documentation of Laboratory Experiments and Data

--	--	--	--	--	--

	Very Little 1	Little 2	Neutral 3	Much 4	Very Much 5	N/A
Interaction with Peers						

Interactions with Ph.D. and M.D. Faculty						
--	--	--	--	--	--	--

Social Events						
---------------	--	--	--	--	--	--

Other:						
--------	--	--	--	--	--	--

7. I was effectively mentored during my internship by:

Research Staff						
----------------	--	--	--	--	--	--

Faculty Mentor						
----------------	--	--	--	--	--	--

Please type your current academic or professional appointment.

--

Please type your institution or employer.

--

THANK YOU! Your participation in this survey will assist in continual improvement of the summer educational program.

Figure 1

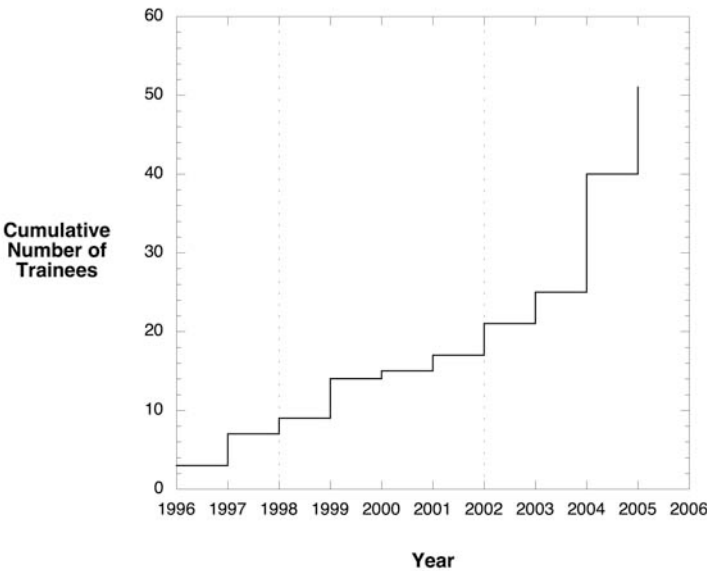


Figure 2

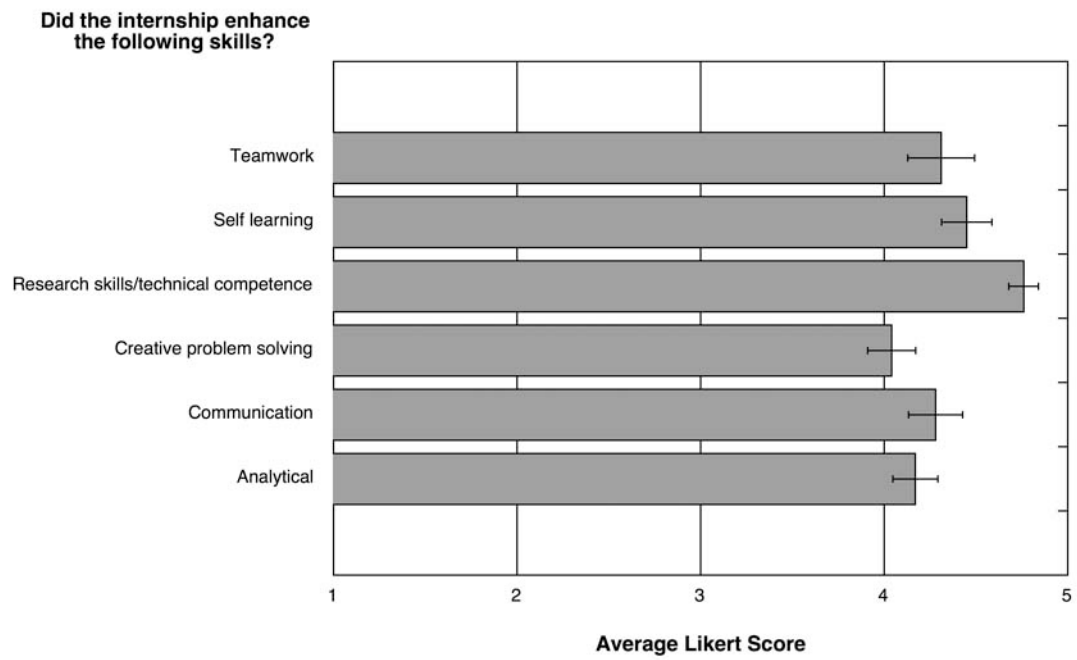


Figure 3

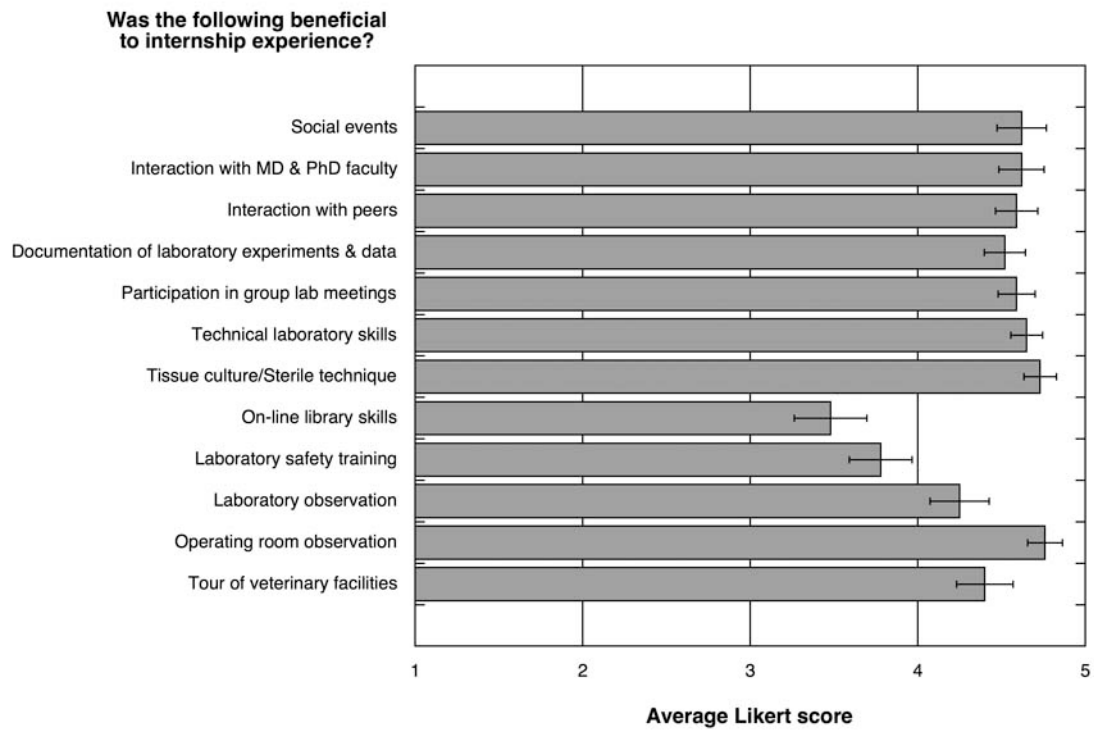


Figure 4

